OFFICE OF NAVAL RESEARCH
PUBLICATION/PATENTS/PRESENTATION/HONORS REPORT
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R&T Number: 3148120---06

Contract/Grant Number: ONR Grant NO: N00014-94-1-0343

Contract/Grant Title: Wavelet-Based Fault-Tolerant Integration and Target
Recognition in Multidimensional Sensor Signal Processing

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a. Number of Papers Submitted to Referred Journal but not yet published: __7__

b. Number of Papers Published in Referred Journals: __10__
(list attached)   1 accepted

c. Number of Books or Chapters Submitted but not yet Published: __1__

d. Number of Books or Chapters Published: __4__ (two are in print; two under review)
(list attached)

e. Number of Printed Technical Report &   Referred Papers: __12__
(list attached)

f. Number of Patents Filed: __none__

g. Number of Patents Granted: __none__
(list attached)

h. Number of Invited Presentations at Workshops or Prof. Society Meetings: __2__

i. Number of Presentation at Workshop or Prof. Society Meetings: __2__

j. Honors/Awards/Prizes for Contract/Grant Employees:
(list attached, this might Include Scientific Soc. Awards/Offices,
Promotions, Faculty Award/Offices etc.)   Nominated for a Chaired Professorship at LSU

k. Total number of Graduate Students and Post-Docs Supported at least 25%, this
year on this contract,grant:
Grad Students __5__ and Post Docs _____

How many of each are females or minorities?
(These 6 numbers are for ONR's EEO/Minority
Reports: minorities Include Blacks, Aleuts
Amindians, etc and those of Hispanic or
Asian extraction/nationality. This Asians
are singled out to facilitate meeting the
varying report semantics re "under-
represented")

[Grad Student Female   __1__
][
][Grad Student Minority   _____
][
][Grad Student Asian e/n   __4__
][
][Post-Doc Female   _____
][
][Post-Doc Minority   _____
][
][Post-Doc Asian e/n   _____

A General Theory of Signal Integration for Fault-Tolerant Dynamic Distributed Sensor Networks

ONR Grant No: N00014-91-J-1306

RESEARCH SUMMARY

Professor S. S. Iyengar
Professor B. J. Jones

September 7, 1994

General Introduction:

The computational issues relating to information integration by multisensor systems and distributed sensor networks are an area of intense ongoing research. Many significant advances have been made recently in the field of sensor integration. This interest in Distributed Sensor Networks (DSNs) technology for information gathering is at least partially due to: a) the development of new technology making DSNs economically feasible to implement and b) the growing complexity of information gathering applications.

The extraction and fusion of accurate information from the noisy and faulty signals returned by many sensors requires the resolution of many problems including: a) the architecture of fault-tolerant and robust distributed sensor networks, b) the reliable synchronization of sensor signals, c) the efficient integration of information in order to minimize communications and processing overhead, and d) the development of efficient computational tools for abstract representation and integration of sensor data.

The sensor fusion process is of interest for the process of human decision making as well as for its applications within automated systems. As scenarios become increasingly complex and the amount of information available grows, the ability to make quality decisions is increasingly dependent on the ability to correctly group and draw correct inferences from large amounts of raw information. Of particular interest is data which is probabilistic in nature, since the current state of mechanical and electrical sensing devices can not provide information of absolute certainty.

Our current research in overcoming sensor uncertainty involves several different approaches. Most often uncertain data can best be handled in a statistical or probabilistic framework, but relevant information can also be found by handling the data using set theory or by analyzing it in a purely geometric manner. This problem is particularly suited for computer science since sensor data must be treated quickly in order to be available for making timely decisions.

It is necessary to consider the formal and computational properties of the sensor fusion process (algorithms, data structures, architectures and complexity.) Of paritcular interest is sensor fusion in a distributed environment and architectures for fault-tolerant sensor integration.

Systems algorithms for distributed sensor networks:

Evaluating distributed sensor networks with systems theory involves the classical problems of solving large linear and nonlinear systems of equations and computing interactions. Solutions to these problems are of applicability beyond the immediacy of the current context. Linear systems in entropy mathematics now have acceptable solution algorithms; however, effective algorithms for non-linear systems are lacking. Moreover, the distributed problem requires all roots in a region to be isolated. In this regard, a new nonlinear systems algorithm that is both effective and efficient has been developed and published.

Interactions, as statistically defined, depend on a linear model. A new concept of interaction that depends on entropy mathematics and is free of model dependent assumptions has been developed and published. Further, a general means of improving the rate

of convergence of virtually any slow moving iterative numerical algorithm has been found. Whereas certain o   systems algorithms initially required 500 iterations to converge, this has been reduc   15 to 50 iterations.

In general, the area of systems theory known as reconstructability analysis has been generalized to the distributed problem. This also involved generalizing and improving systems algorithms in the absence of complete information. These algorithms have broad applicability in systems theory and numerical mathematics.

Wavelet based sensor integration:

Multiresolution analysis can be used in filtering out robust peaks in the overlap functions obtained from abstract sensors to pr   e fault tolerant sensor estimates in Distributed Sensor Networks. This technique is   c   tive when the number of sensors is very large and the number of tame sensors is a o v y large. The idea essentially consists of constructing a simple function from the outpu of the sensors in a cluster and resolving this function at various successively finer scales ot resolution to isolate the region over which the correct sensors lie.

Topics of Current Research:

The following topics are our current research subjects:

1) Wavelet based distributed sensing and fault-tolerant sensor integration.

2) Computational frameworks for distributed sensing and fault-tolerant sensor integration.

3) Design of fault-tolerant architectures for distributed sensor integration.

4) Computational complexities of the problem of distributed detection.

5) Issues related to recording of events and synchronization in distributed sensor networks.

6) Derivation and simulation of statistical filtering and deterministic methods for competitive and complementary sensor fusion in target detection and tracking systems.

Attached to this report is a list of publications resulting from this research.

RESEARCH PUBLICATIONS

List of books accepted/published:

1. S. S. Iyengar, H. Min, and L. Prasad, **Advances in Distributed Sensor Integration: Applications and Theory**, Prentice-Hall, 1994.

2. L. Prasad and S. S. Iyengar, **Introduction to Wavelets**, Academic Press, 1994.

3. C. Xavier and S. S. Iyengar, **Introduction to Parallel Algorithms**, Tata-McGraw Hill, 1994, (under review).

4. S. S. Iyengar and G. Seetharaman, **Multisensory Perception of 3-Dimensional Scene**, Prentice-Hall, 1994, (under review).

List of papers accepted/published in refereed journals:

1. L. Prasad and S. S. Iyengar, " A General Computational Framework for Distributed Sensing and Fault Tolerant Sensor Integration", **IEEE Transactions on SMC**, July 1994.

2. A. A. Nanavati, S. S. Iyengar, and A. El Amawy, "Topological Properties of the Recursive Petersen Architecture," (To appear in **Journal of Computer and Mathematical Modeling** (1994).)

3. B. Jones and S. S. Iyengar, "Approximate Root Isolation for Nonlinear Systems by Monte Carlo", **International Journal of Computers and Mathematics with Applications**, Vol. 27, No. 7, pp. 1-5, 1994.

4. R. Rao and S. S. Iyengar, "Bin Packing by Simulated Annealing", **International Journal of Computer Mathematics**, Vol. 27, No. 5, pp. 71-82, 1994.

5. S. S. Iyengar, D. N. Jayasimha, and D. Nadig, "A Versatile Architecture for Distributed Sensor Integration Problem," **IEEE Transaction on Computers**, Vol. 43, No. 2, pp. 175-185, 1994.

6. L. Prasad, S. S. Iyengar, R. Rao, and R. L. Kashyap, "Fault-tolerant Integration of Abstract Sensor Estimates using Multi-resolution Decomposition," **Physical Review**, Vol. 49, No. 4, pp. 3452-3460, 1994.

7. N. S. V. Rao, S. S. Iyengar, and R. L. Kashyap, "Computational Complexity of Distributed Detection Problems with Information Constraints," **Journal of Computers and Electrical Engg.**, Vol. 19, No. 6, pp. 445-451, 1993.

8. N. S. V. Rao, S. Gulati, S. S. Iyengar, and R. N. Madan, "Guest Editorial: Parallel and Distributed Computing for Intelligent Systems," **Journal of Computers and Electrical Engg.**, Vol. 8, pp. 1-4, 1993.

9. S. S. Iyengar and W. Deng, "A New Probability Relaxation Scheme and Its Application to Edge Detection," **Journal of Pattern Recognition**, (To appear in 1995.)

10. S. Rajanrayanan, S. S. Iyengar, R. Srihar, and R. L. Kashyap, "An Optimizing Distributed Algorithm for Recognizing Mesh-Connected Networks," **Journal of Theoretical**

Computer Science, Vol. 20, No. 1, pp. 261-278, 1993.

Paper under revision:

1. Y. Wu, S. S. Iyengar, and Hla Min, "An Efficient Edge Detection Algorithm," Submitted to **Computer Vision, Graphics and Image Processing**.

List of papers submitted to refereed journals:

1. S. S. Iyengar and D. Nadig "Using Temporal Intervals for Synchronization in Real Time Distributed Systems," Submitted to **Electronic Encyclopedia**.

2. R. R. Brooks and S. S. Iyengar "Averaging Algorithm for Multi-Dimensional Redundant Sensor Arrays: Resolving Sensor Inconsistencies," Submitted to **Signal Processing**.

3. V. G. Hegde and S. S. Iyengar "Efficient Distributed Planarity Testing Algorithms in the context of DSN," Submitted for publication.

4. R. R. Brooks, N. S. V. Rao, and S. S. Iyengar "Resolution of Contradictory Sensor Data" Submitted to **Scientific American**.

5. B. J. Jones and Deky Gouw "The Interaction Concept of K-Systems Theory," Submitted to **Int. Journal of General Systems**.

6. B. J. Jones and S. S. Iyengar "Signal and Noise: Towards a General Theory of Algorithms," Submitted to **Int. Journal of General Systems**.

7. B. J. Jones "Proving Formula Correctness," Submitted to **Cybernetica**.

List of papers in refereed conference proceedings:

1. D. Nadig and S. S. Iyengar "A New Architecture for Distributed Sensor Integration," Proceedings of the **IEEE SouthEastCon**, April 1993.

2. R. R. Brooks and S. S. Iyengar "Algorithm for Resolving Inter-dimensional Consistencies in Redundant Sensor Arrays," **Proceedings of Indo-US Workshop on Parallel and Distributed Signal and Image Integration Problems**, June 1994.

3. S. Q. Zheng, J. Shik, and S. S. Iyengar "Efficient Maze-Running and Line-Search Algorithms for VLSI Layout," **Proceedings of IEEE SouthEast Conference**, March 1993.

4. S. Trivedi, B. Jones, and S. S. Iyengar "Reconstruction of Possibilistic Systems with Incomplete Information," **Proceedings of 32nd Southeast ACM Conference**, March 1994.

5. P. Graham and S. S. Iyengar "Double and Triple Step Incremental Linear Interpolation," **Proceedings of Applied Computing**, Feb. 1993.

6. S. Trivedi, B. Jones, and S. S. Iyengar "Reconstruction Algorithms," **Proceedings of the 7th SIAM Conference on Discrete Mathematics**, July 1994.

7. R. L. Rao and S. S. Iyengar "A Stochastic Approach to the Bin Packing Problem," **Proceedings of the 1994 ACM Symposium on Applied Computing**, Phoenix, March 6-8, 1994.

8. D. Nadig, S. S. Iyengar and D. N. Jayasimha "A Versatile Architecture for Distributed Sensor Integration," **Proceedings of IEEE-SouthCon**, 1993.

9. Y. Wu, S. S. Iyengar, R. Jain and S. Bose "Shape from Perspective Trihedral Constraint," **Proceedings of IEEE Computer Vision and Pattern Recognition**, New York, June, 1993.

10. W. Deng, S. S. Iyengar, and N. E. Groner "A Fast One-Pass Thinning Algorithm," **Proceedings of First International Workshop on Parallel Processing**, Bangalore, India, December 27-30, 1994.

11. S. Vendatham, S. Das, S. S. Iyengar "Near Optimal Solutions to the Grid Connection Problem," **IEEE World Conference on Computational Intelligence**, Orlando, Florida, June 1994.

12. W. Deng, and S. S. Iyengar "A Fast Parallel Thinning Algorithm for the Binary Image Skeletonization," **International Workshop on Parallel Processing**, Bangalore, India, pp. 27-30, 1994. (To appear December 1994)

Research papers in progress:

1) Spline Wavelets: A New Approach to Finite Impulse Response (FIR) Filter Design.

2) Wavelet Based Distributed Sensing and Fault-Tolerant Sensor Integration.

3) Scaling and Temporal Characterization of Sensor Integration Problem in Distributed Environments. This is an extension of Dr. Madan's work on Maximum Entropy techniques.

4) Interval-based Synchronization in Real-Time Distributed Sensor Systems.

5) Distributed Conferencing System for 2D Graphics Design.

6) Resolution of Complementary and Competitive Sensor Tracking Problems with Kalman Filters and Cloud Removal Techniques.

7) Efficient Algorithms for Resolution of Contradictory Data.

8) Interactive Equations in Reconstruction Algorithms for Distributed Systems.

Books in progress:

1) Fundamentals of Multi-Sensor Fusion: Theory and Applications